THE NEW ZEALAND STRONG MOTION EARTHQUAKE RECORDER NETWORK

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SYNOPSIS

The network of strong-motion earthquake recorders, maintained throughout New Zealand by the Engineering Seismology Section of the Department of Scientific and Industrial Research, is described. The instruments are either deployed as ground instruments to measure potential earthquake attack on structures, or in structures, e.g. buildings, dams and industrial installations, to record structural response. Details are given of installation of instruments, maintenance, laboratory work, record retrieval and digitisation, costs and staffing for the network. Future developments mooted include an improved digitising system, the introduction of an improved version of the existing mechanical-optical instrument in 1979, and, in the long term, the introduction of an entirely new digital recorder, having an electrical output from its accelerometers, which will make possible the transmission of data by telephone or radio link.

1. INTRODUCTION

The Physics and Engineering Laboratory first became interested in earthquake recording in the 1950s as the result of requests from designers about the effect of earthquakes in New Zealand on engineering structures. Instruments were designed and developed and a network of strong motion recorders has been gradually built up throughout the country. The network was first described in the Bulletin of the New Zealand Society for Earthquake Engineering in 1970 (1) when there were 77 three component records and 74 two component (non time-base) recorders. By the end of 1978 the number of three component recorders had risen to 125 while the number of two component records remained the same, the increase in the number of three component recorders resulting mainly from requests for installations in important structures such as power stations, bridges and buildings.

With an increasing number of records accumulating at the Laboratory, emphasis is now being placed on their digitisation and routine analysis, so that they can be used in research and in the computerised design of structures, thereby enabling improvements to be made in earthquake-resistant design.

2.0 THE INSTRUMENTS

2.1 MO2 Accelerograph (Fig. 1)

The primary instrument of the New Zealand network is type MO2 (mechanical-optical) accelerograph, which records accelerations at its location in three orthogonal directions, from the motions of damped pendulums. It records high definition traces on unperforated 35 mm film. Time marks are provided which are controlled either by a tuning fork clock, or more recently by a crystal oscillator, imprinted along the edge of the film at 0.02 second intervals. Starting is initiated by a vertical sensing geophone. For inter-connected accelerographs, any one instrument started by an earthquake acceleration will also start all the others in that system. The film cassette holds sufficient film for nine records, each of 47 seconds duration.

The accelerograph is fully sealed and operates off a 12 volt dry cell power supply. More detailed information on the accelerograph is outlined in the instrument manual (2).

2.2 MO1 Accelerograph

The MO2 was developed from the type MO1 three component accelerograph and 24 of the type MO1 are still in operation in the network. They are gradually being replaced by the type MO2 recorder, as they do not have the facility for inter-connection or time marking, and are not sealed.

These instruments are mainly situated in telephone exchanges as this gives the best environment for successful operation.

2.3 SP2 Accelerograph

The two component SP (scratch plate) accelerographs (Fig. 2), recording accelerations in the horizontal plane only, were the first instruments to be used in the network. Although limited in accuracy and lacking a time base, they have given records at many points where otherwise none would have been available, notably during the Inangahua earthquake. When installed beside a MO2 accelerograph they have provided a valuable back-up.

The accelerograph is based on an inverted pendulum with an undamped period of 0.06 seconds, and a damping factor of about 60% of critical, the damping being provided by silicone oil. The relative displacement of the pendulum weight, with respect to the base, is a measure of the amplitude and direction of the horizontal acceleration of the instrument (2). The movement of the pendulum weight is amplified by the lightweight extension arm into which is plugged a smoked

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glass disc. A fine line, (about 0.01 mm wide) is inscribed on the smoked surface of the moving disc by a specially sharpened steel needle, this giving the acceleration record. The instrument has proved to be very reliable and the only cause of inoperation has been vandalism.

3. THE NETWORK

3.1 Instrument Distribution

The distribution of MO1 and MO2 recorders throughout the country is illustrated in Figure 3, and the breakdown in terms of buildings, dams and bridges and individual instruments is given in Table 1. The distribution of SP recorders is shown in Figure 4. The build-up of MO instruments since 1965 is shown in Figure 5, the most rapid increase in numbers occurring in the two years following the Inangahua earthquake in 1968. Of the total of 125 three component recorders distributed throughout the country only 15 MO2s and 19 MO1s were purchased by the Laboratory, the remainder either being purchased by government departments or by private building owners on the advice of consulting engineers. Agreement has been obtained for the installation of a further 29 instruments in buildings, bridges and power stations (Table 2).

From Table 1 it is seen that all of the instruments purchased by other authorities have been required for particular structures, while those purchased by PEL have been for ground installation, either to fill gaps in the network (22 instruments) or for microzone installations in the Wellington and Hutt Valley areas (12 instruments). All the projected installations listed in Table 2 are for structures, over half of which, 18 instruments, are for the Wellington area.

The instruments in the network have been deployed to gather data of two kinds to promote the design of more efficient and economical earthquake resistant structures. Firstly, ground accelerations are recorded so that designers have a wider data base from which to select the most appropriate earthquake loadings for use in structural design. Secondly, accelerations are recorded at several locations throughout major structures to monitor their performance during strong-motion earthquakes (Fig. 6).

Most ground based instruments are located in areas of highest seismicity, which are indicated by the map prepared by the Seismological Observatory showing the occurrence and distribution of earthquakes in New Zealand since 1840 (Fig. 7). This shows that the major earthquakes occur in a zone which is along a band running roughly between Milford in the south-west to Cape Runaway in the north-east. Although the Laboratory does not intend to increase the total number of instruments in the network, a comparison between this map and the distribution of MO2 instruments (Fig. 3) indicates that more instruments of this type should be added to fill in gaps along this band, particularly in the area north of the Wairarapa through to Napier. Some redistribution is possible, however, e.g. no records have been obtained from Auckland from the time the network was first started and it is less likely that performance data into the ductile range will be obtained from the instrumented tall buildings there. Perhaps therefore the number of instruments in these buildings should be reduced in favour of ground-based instruments only in Auckland. Also, improvements are being carried out by selectively replacing SP instruments by MO2 instruments in preferred locations, the service time for the two instruments being about the same.

3.2 Local Microzone Networks

Two local networks in the Hutt Valley and in the Te Aro district of Wellington City have been set up to study the influence of local geological features and of soil properties on ground motion.

3.3 Networks at Dam Sites

Instrument arrays have been installed at dam sites, either to study local seismicity and microzone effects during a site investigation (e.g. Atene) or to study structural response, as at the earth dams of Matahina and Benmore. One particular use of an array of instruments on a dam is in recording the effect of any local earthquakes which may be caused by filling the lake behind the dam. Improved knowledge of the seismic behaviour of dams is of great importance from the safety aspect.

3.4 Instruments in Industrial Installations

The safety aspect is also of considerable importance in industrial installations. Two MO2 recorders have recently been installed at the Maui A offshore gas rig which will enable the loading on the structure in the event of an earthquake to be assessed. Similar safety aspects apply to the installation of a recorder at the Karioi wood-pulp mill where it will be possible to assess loadings on the machinery and pipework and its fixings. In addition, a request has recently been received for an installation in a thermal power station, together with an earthquake trigger which will give a warning to engineers in noisy areas that an earthquake is taking place, thereby allowing emergency measures to be taken. Such a trigger has already been manufactured for an industrial installation from standard MO parts, and a commercial device should soon be available.

3.5 Instrument Installation

The instruments are normally bolted firmly down to a concrete plinth which can be set conveniently above the normal concrete floor level. In the field the plinth needs to be keyed thoroughly to the surface for which motion is to be recorded. Occasionally instruments may be bolted to a vertical concrete wall in bridge or building applications. They are protected by a padlocked steel case.

3.6 Instrument Siting

Because of the risk of vandalism of field instruments, instruments of the main ground network are normally located in the basements of smaller public buildings such as post offices, telephone exchanges and fire stations. Within multi-storey buildings instruments are located in storerooms or

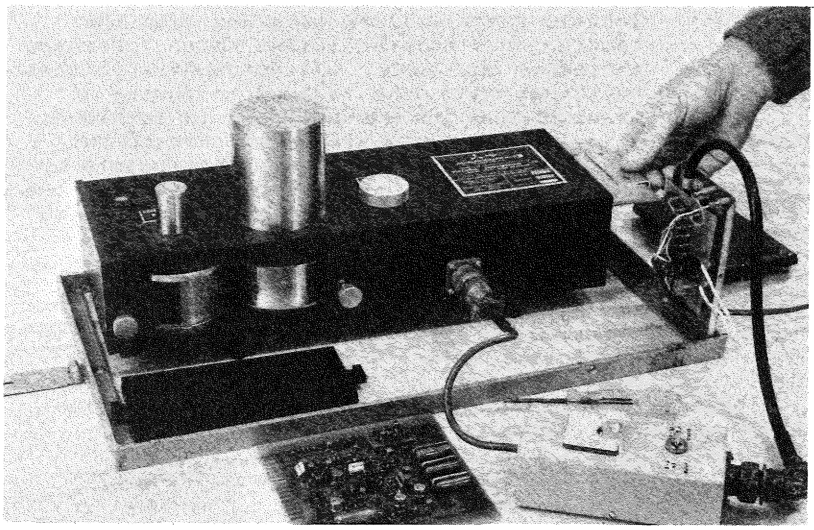

FIG. 1 MO2 Accelerograph - checking circuits

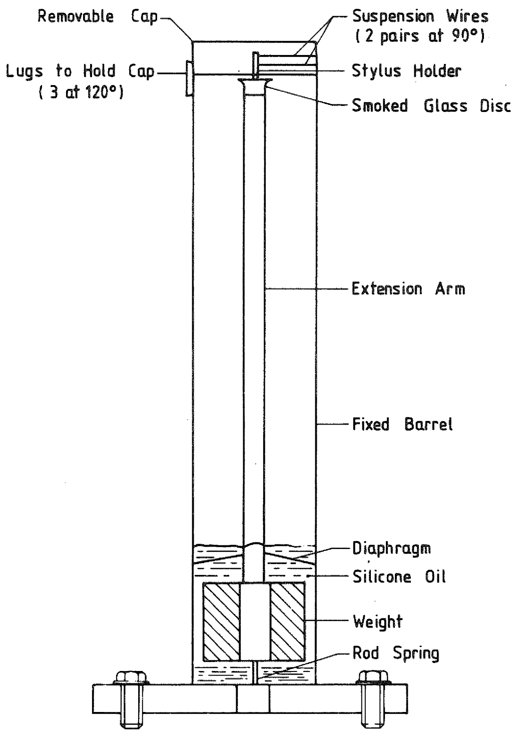

FIG. 2 Scratch plate instrument

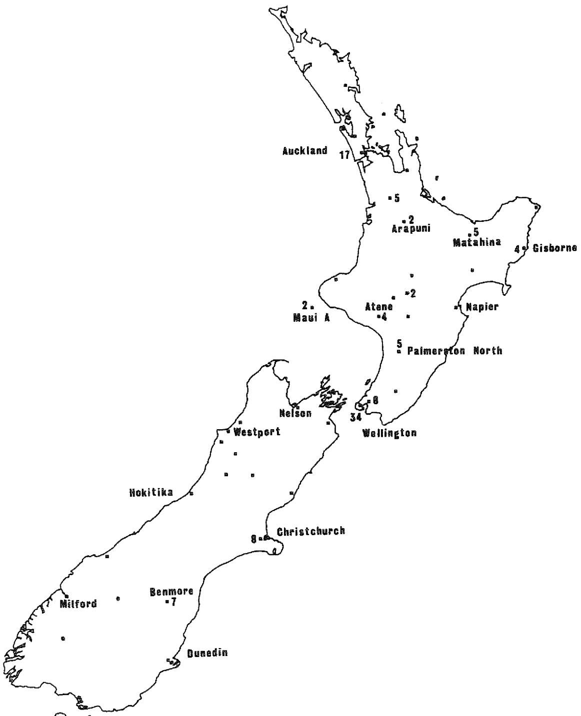

FIG. 3 Distribution of MO2 Accelerographs throughout New Zealand (February 1979)

FIG. 4 Distribution of scratch plate instruments throughout New Zealand (February 1979)

closets which are often to be found adjacent to lift shafts and stairs in the core of the building. A check is made with the building designer to ensure that the instruments are located at the most desirable points within the structure. Damp sites can cause sticking in the cassettes and, at such locations, a drying agent is kept in the instruments to absorb moisture.

3.7 Maintenance of Network

From the point of view of servicing the instruments, New Zealand is divided into 6 zones (Figure 8, with zone 6 being Wellington and the Hutt Valley), all having approximately equal service time. In early 1969 a strict service schedule was adopted in which each of the instruments was visited at intervals of close to 6 months. Where possible a shorter interval between visits was adopted during the year or so following installation. This system improved the reliability of the instruments, while the personal contacts established during the regular visits, and the frequent explanations of the working of the instruments, prevented them being broken into for examination by inquisitive local people, which had previously occurred from time to time.

As the reliability of the MO2 recorders increased it became less necessary to carry out servicing every 6 months and in 1975 the service interval was extended to 8 months, and remains at this interval, to reduce the servicing load brought about by the increased number of instruments.

3.8 Laboratory Work on Instruments

Although the MO2 accelerograph is manufactured commercially under licence, the calibration of each sensing unit is still carried out by the Laboratory using a static calibration method, as already outlined[1], and the calibration constants are stored in a computer file which can be accessed during record processing. Performance checks are also carried out on the unit before installation in the field.

Depending on the availability of spare instruments, one or two MO2 recorders are replaced on each zone visit with fully overhauled instruments, upgraded to the latest design specifications. At the present time this includes the fitting of crystal oscillators, for time marking from the start of the trace, replacing the obsolescent tuning fork circuit previously fitted. Interconnection facilities are now standard for all instruments. With a total of 125 instruments to be serviced the replacement programme will take about 10 years with the staff available.

3.9 Record Processing

The work of the processing and storing film records is carried out entirely by the Engineering Seismology Section of the Laboratory in order to ensure that earthquake records are not lost. Any events recorded are identified and copied using a direct print method. All further record processing, such as digitising, is carried out using film copies to avoid damage or loss to the original film record, which is archived.

Sections of the test film from each instrument brought back from the service visits are filmed and checked against samples obtained previously from the same instrument. In this way any faults in film transport or trace definition can be noted and corrected on the next visit.

Scratch plate slides returned from sites are examined for the pattern indicating a recorded earthquake. A photograph is then made of the pattern which is filed; plate slides showing exceptional patterns are also filed, while those showing no record are discarded. New slides are placed in each instrument on every service trip.

3.10 Record Publication and Digitisation

All records of earthquakes obtained from MO accelerographs in the years 1965 to 1972 have been published in the form of a copy of the film trace. The records from 1973 onwards have not been published because of plans for a more effective presentation of data, as was done for the 1976 Milford earthquake[4]. Staff shortages and the priority given to instrument operation and maintenance have delayed the introduction of the new method of publication but substantial progress is now being made. The practice of publishing copies of the traces is to be discontinued in favour of a system for publishing copies of records in digital form. About one dozen selected records have so far been digitised, including those from earthquakes which occurred at Milford in 1976, Atene 1973, Inangahua (aftershocks) 1968, and Wellington (Vogel Building) 1977. It is hoped that modern digitising equipment will be purchased shortly which will increase the numbers of records available in this form. A summary of those records with peak accelerations greater than 10%g is given in Table 3. Altogether, 246 records have been obtained which have shown accelerations greater than 1%g.

3.11 Costs

3.11.1 Capital Cost

The cost of a single MO instrument is approximately $2,000. Thus the investment in the MO network alone is $250,000.

3.11.2 Servicing Costs

The cost of servicing the existing network of 125 MOs and 74 SPs is as follows per annum:

	$
Spare parts purchased and miscellaneous laboratory equipment	1,000
Batteries (No. 6 cells at present)	2,000
Mileage - 90,000 km at $0.1345/km	12,000
Travelling expenses for 2 NO. staff for 5 x 10 day trips	4,000
Salaries and overheads for two technicians (approximately)	40,000
	$59,000

It is apparent that if it is desired to increase the size of the network then the servicing costs do not increase linearly with the number of instruments as the mileage of 90,000 km already covers visits to most parts of New Zealand.

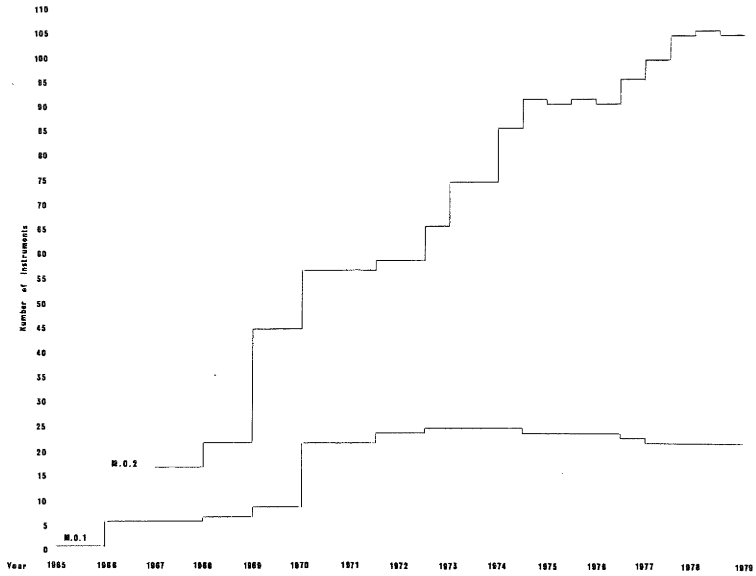

FIG. 5 Numbers of strong-motion recorders in New Zealand since 1965

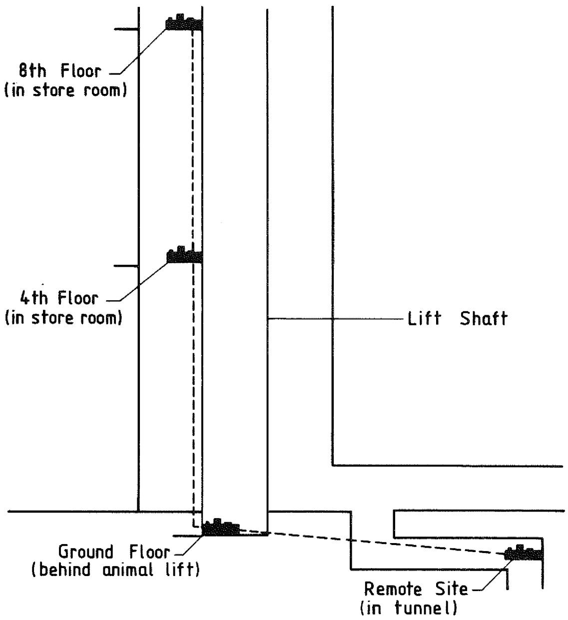

FIG. 6 Interconnected system of accelerographs for building (Massey University)

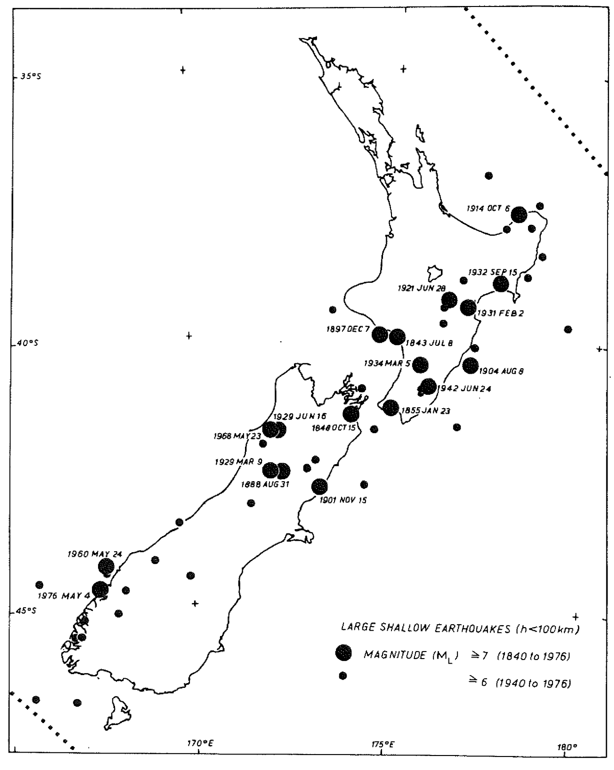

FIG. 7 Occurrence and distribution of earthquakes throughout New Zealand (from Seismologiacal Observatory)

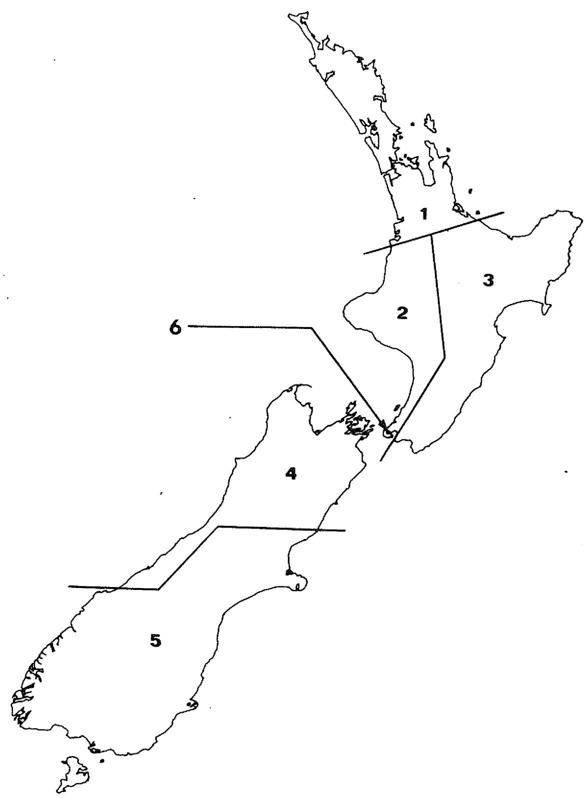

FIG. 8 Service Zones for instruments

3.12 Staffing

Two technicians are employed full time in maintaining the network of 125 MO recorders and 74 SP recorders and in upgrading them to new specifications. Each of the six zones requires 32 working days of each technician's time and a further 32 days per year are spent in preparing reports and exhibitions and in general office administration. This gives times allocated as follows:

Description of Work	Time Spent per zone (days)		Total days for 2 technicians per annum for 6 zones
	Technician No.1	Technician No.2	
Site visits	8	2	60
Servicing & upgrading returned instruments	6	-	36
Instrument development	4	-	24
Processing film & SP slides	3	4	42
Record work including digitising & posting on worldwide network	4	12	96
Preparing films, batteries, SP slides and other stores for next trip	3	10	78
Administration for visits, including booking vehicles and correspondence with authorities and site representatives	4	4	48
Sub-total per zone	32	32	
Preparing reports and exhibitions and office administration			64
TOTAL DAYS FOR 2 TECHNICIANS			448

In addition, further assistance is co-opted as required to generally assist in the work in a non-specialist way, e.g. to assist in carrying equipment, running leads, or acting as a station reporter when checking interconnected systems. The amount of time involved is about 6 man days per zone, i.e. 36 man days per year, but this time is not included in the table, as recruitment is as required for each trip, made either from the Laboratory or through local DSIR establishments, e.g. at Christchurch or Auckland.

The table shows that only 60 working days are spent in the field in servicing instruments. This represents only about 1/8th of the total time, the remainder being spent in providing a back-up for the service. Thus while offers have been made from time to time by local authorities to service instruments, if adopted this would only represent an increase of about 1/8th in the number of instruments which could be serviced, which would largely be nullified by the communications problems which would exist between the Laboratory and the zones. It is felt therefore that the present arrangement of servicing the network from a central source is the best one.

4. FUTURE DEVELOPMENTS

In 1979 it is proposed to introduce a major upgrading of the MO2 instrument, to be called the MO2A. A new lightweight geared motor will be fitted together with an electronic clutch which will replace the mechanical clutch, which has occasionally given trouble. A press-button film release will also be introduced to make film rewinding easier and hence minimise scratches and static electricity on the film. Also under development is a facility to record the elapsed time from the last visit to the event recorded. This will ensure the correlation of records with other instruments in the network recording the same event and facilitate identifying a record with a particular earthquake. The latter will enable epicentral distances to be estimated from the epicentre determinations of the Seismological Observatory.

In a few years it may also be possible to supplement and eventually replace the film recording system with an electronic bubble memory on which the record is made in digital form, the sensing unit being three orthogonal accelerometers with electrical output. In this way occasionally troublesome film or magnetic tape transport will be avoided in the instruments. It will also eliminate the need for film processing and record digitising. Such a device could also be used as a trigger with little modification. In addition, a record could be transmitted by a radio link or integrated into the telephone system to allow the data to be obtained by dialling the instrument. These facilities are important where information on the condition of important installations, e.g. unmanned dams, is required immediately following an earthquake.

5. REFERENCES

1. Skinner, R. I., Stephenson, W. R. and Hefford, R. T., "Strong-Motion Earthquake Recording in New Zealand". Bull. of the N.Z. Nat. Soc. for Earthq. Eng., Vol. 1, No. 4, p.31 (1970).
2. Physics and Engineering Laboratory DSIR. "Type MO2 Accelerographs (Skinner-Duflou) Installation and Operating Manual". (Available through manufacturers: Victoria Engineering, Lower Hutt.)
3. Skinner, R. I. and Duflou, P. C. J. (1965) "New Strong-Motion Accelerographs". Proc. Third World Conference on Earthquake Engineering.
4. Hodder, S. B., Skinner, R. I., Hefford, R. T. and Randal, P. M., "Strong Motion Records of the Milford Sound Earthquake 1976, May 4", Bull. of the N.Z. National Soc. for Earthq. Eng., Vol. 11, No. 3, September 1978.

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TABLE 1

INSTALLED THREE COMPONENT ACCELEROGRAPHS
(as at December 1978)

Location	No. of Instruments MO2	No. of Instruments MO1	Owner
DAM SITES			
Arapuni	2		
Atene	3		
Benmore	7		
Matahina	5		MWD
Moawhango	3		
Mokihinui	1		
Te Kuha	1		
BUILDINGS			
Auckland			
Civic Centre	6		Auckland City Council
Customhouse	3		State Services Commission
Savings Bank	3		Auckland Savings Bank
University Science Bldg	5		MWD
Hamilton			
Police Station	4		MWD
Wellington			
Charles Ferguson	4		MWD
Challenge House	4		Challenge Corpn. Ltd
Dalmuir House	3		Presbyterian Church of NZ
Postal Centre	4		MWD
Reserve Bank	3		Reserve Bank of NZ
Rutherford House	4		MWD
Vogel Building	4		MWD
Massey			
University	4		MWD
Christchurch			
Police Station	4		MWD
University Library	4		MWD
BRIDGES			
Shell Gully (Wellington)	3		MWD
South Rangitikei Bridge	1		NZR
FACTORIES, POWER STATIONS, ETC.			
Tuai Hydro Station		1	PEL
Karioi Pulp Mill	1		Winstone Samsung Ind Ltd
Maui A	2		Shell, BP, Todd
Kaipara Harbour Investigation	2		MWD
Haywards Sub Station	1		NZED
Inangahua	1		PEL
c/f	92	1	

Location	No. of Instruments MO2	No. of Instruments MO1	Owner
b/f	92	1	
INDIVIDUAL INSTRUMENTS			
Zone 1			
Hamilton P.O.		1)	
Thames P.O.	1	)	PEL
Whangarei Tel. Ex.		1)	
Zone 2			
Hutt Valley Microzoning			
Belmont El. Substation	1	)	
Elizabeth St. Pumping Stn.	1	)	
Gear Meat Pumping Stn.	1	)	PEL
Institute Nuclear Science	1	)	
Naenae Reservoir	1	)	
PEL		1)	
Woollen Mills El. Substation	1	)	
Wellington Microzoning			
Airport	1	)	
ANZ Bank	1	)	
Church Street Sub Station	1	)	PEL
Vivian Street Gray & Elliot	1	)	
Library, Central	1	)	
Zone 3			
Masterton Tel. Ex.		1)	
Napier Tel. Ex.		1)	
Te Araroa High School		1)	PEL
Turangi		1)	
Zone 4			
Cheviot P.O.		1)	
Blenheim Tel. Ex.		1)	
Haast P.O.		1)	
Hokitika P.O.		1)	PEL
Muruia Springs Hotel		1)	
Nelson Tel. Ex.		1)	
Reefton, Forest HQ	1	)	
Westport Tel. Ex.		1)	
Zone 5			
Dunedin P.O.		1)	
Invercargill Tel. Ex.		1)	
Milford Hotel	1	)	PEL
Te Anau		1)	
Wanaka		1)	
TOTAL	106	19	

TABLE 2

AGREED FUTURE INSTALLATIONS OF MO2 ACCELEROGRAPHS

Location	No. of Instruments	Owner
BUILDINGS		
Wellington		
Hospital	3	Wellington Hospital Board
Freyburg	1	MWD
Beehive	5	MWD
BNZ	3	BNZ
William Clayton	3	MWD
Christchurch		
Postal Centre	3	MWD
Law Courts	3	MWD
BRIDGES		
South Rangitikei	3 (more)	NZR
Bowen Street Wellington	3	MWD
FACTORIES, POWER STATIONS, ETC.		
Marsden Point	1	NZED
Huntly	1	NZED
TOTAL	29	